RESEARCH DEPARTMENT

MULTIPATH PROPAGATION IN BAND II (88-95 Mc/s) AND ITS EFFECT ON F.M. RECEPTION — I

Report No. E-056

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THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

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SUMMARY

A preliminary investigation has been made into distortion caused by multipath propagation within the service area of the Wrotham v.h.f. station, which works in Band II (88-95 Mc/s). Distortion is most commonly caused by signals that have been reflected by hills or built-up areas and have travelled at least 10 km further than the direct signal. The strength of the reflections observed is greatly influenced by the position of the receiving aerial when inside a building. The distortion can be reduced by the use of a directional aerial and/or a receiver that effectively suppresses amplitude modulation.

1. INTRODUCTION

It has long been known that non-linear distortion of the a.f. signal can be caused when a frequency-modulated carrier is received by two or more paths as a result of reflection from nearby or distant objects. Nevertheless reports from listeners during the period of experimental transmissions from Wrotham (1950-1954) gave no reason to suspect that this effect would be important. But when a regular public service was commenced, and commercial receivers were sold in large numbers, complaints of non-linear distortion began to come in. Some of these pointed to multipath propagation as the cause. This report describes a preliminary investigation into the nature and magnitude of the problem.

2. DISTORTION PRODUCED BY MULTIPATH PROPAGATION

If a transmission frequency-modulated by a pure tone reaches a receiving aerial after traversing two or more paths of different lengths, the resultant signal will be both amplitude- and frequency-modulated by harmonics of the modulation frequency. The relative amplitudes of these harmonics depend in a complicated manner on the path difference, modulation frequency, and the peak frequency deviation[1, 2, 3]. When the modulation is not a pure tone, the distortion products will include sum and difference terms of various orders in addition to harmonics. The distortion products increase with the relative amplitudes of the delayed signals and tend to be of higher order with long path-differences and large deviations. The distortion products present in the audio-frequency output of the receiver are greatly reduced if the receiver is insensitive to amplitude modulation.

No attempt has been made during the investigations described in this report to analyse the harmonic content of the audio output of a receiver, although some listening tests have been carried out using both typical commercial receivers and a receiver having an a.m. suppression ratio of the order of 30 dB. Attention has been concentrated mainly on measuring the relative amplitudes and path differences of the delayed signals at a number of sites, using the equipment described in the next section.

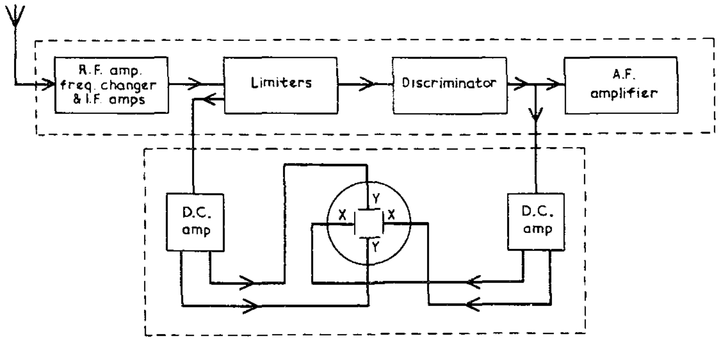

Fig. 1 - Block schematic diagram of measuring equipment

3. METHOD OF MEASUREMENT

A receiver and oscilloscope were arranged as shown in Fig. 1. A potential difference proportional to the instantaneous amplitude of the signal, derived from the limiter grid circuit, was applied to the Y plates. At the same time a potential difference proportional to the instantaneous frequency deviation, taken from the output of the discriminator, was applied to the X plates. In the absence of delayed signals the instantaneous amplitude remains constant as the frequency varies and the oscilloscope trace is a horizontal straight line. If a reflected signal is received in addition to the direct signal their phase difference, and hence the amplitude of their resultant, varies with the instantaneous frequency, and a trace of the type shown in Fig. 2 is obtained. The ratio of the amplitudes of the two signals is equal to a/b and it may be shown that their path difference in km is given by $300/f$, where f is the frequency separation between adjacent maxima of the trace, in kc/s. In general several reflected waves are received simultaneously and the shape of the trace is complicated (Fig. 3). Nevertheless, it is often possible to measure the amplitudes and path differences of the principal components with reasonable accuracy.

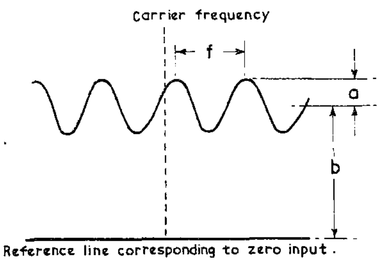

Fig. 2 - Type of display obtained on oscilloscope

It should be pointed out that the above formulae are correct only if the measuring equipment

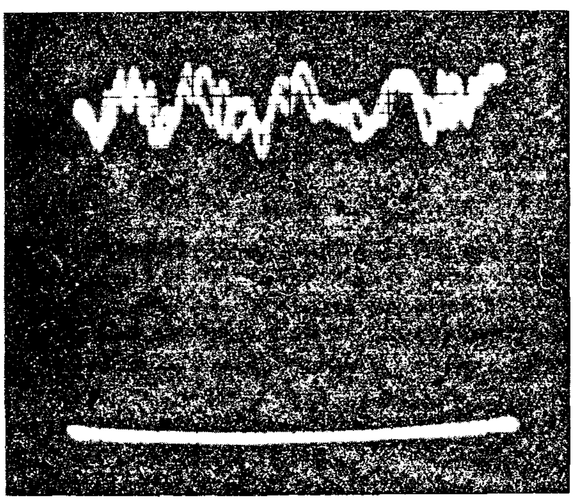

Fig. 3 - Trace obtained at a typical site using a correctly oriented dipole

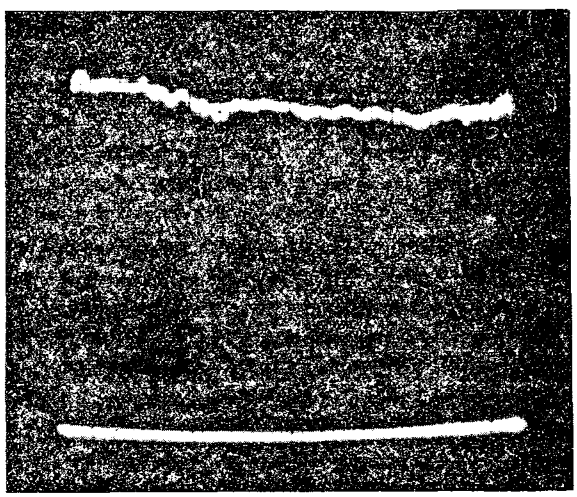

Fig. 4 - Trace obtained at the same site using a 4-element Yagi aerial

is perfectly linear and has a flat frequency response. Errors can be caused by

(a) A non-uniform i.f. response in the receiver.

(b) A non-linear discriminator characteristic.

(c) De-emphasis in the receiver, causing reduction of the horizontal deflection and phase shift for high modulation frequencies.

(d) A non-linear X or Y deflection on the oscilloscope.

(e) A non-linear characteristic of the rectification at the limiter grid.

(f) An insufficiently flat frequency response of the amplitude detector or Y amplifier. The upper frequency limit is required to be many times the highest modulation frequency.

In the equipment used, precautions were taken to minimize these effects. The most important remaining source of error was (e), but corrections have been made where necessary to allow for it.

Owing to phase shift in the X and Y amplifiers of the oscilloscope and their connections a better trace is obtained when using a low modulation frequency. When possible, 90 c/s tone was used for modulation when making measurements, but reasonable results were obtained using programme modulation.

4. PRELIMINARY INVESTIGATION

4.1. General

Preliminary measurements were made to investigate the magnitudes and path differences of reflected signals, the type of localities in which the reflections were greatest, and the variation of field strength which was likely to occur in such areas. The measurements were performed with an omnidirectional aerial at a height of about 12 ft (3·7 m) mounted on a van which had a wooden body.

In built-up areas it was found that reflected signals having amplitudes of up to 50% of the direct signal amplitude occurred, even though the path differences between the two signals were 2 km or more. In such places the field strength was found to vary over a 4 to 1 range, and the relative magnitude of the reflected signal was usually greatest when the total field strength was least.

In hilly areas positions were found at which the two signals were of equal magnitude, but these were generally in localities where the total field strength was so low that good reception would not be possible in any case. In regions of adequate field strength the relative amplitude of the reflected signal was never greater than 50%.

In residential areas away from large objects such as gasholders the relative amplitudes of the reflected signals were of the order of 10% to 20% with the aerial

at a height of 12 ft (3·7 m). These figures include both long and short path-difference reflections.

At a number of open sites measurements of the direction and path difference of the reflected wave were made in order to determine the position of the reflecting object. These measurements were possible only when one predominant reflection was observed. In the case of strong reflections with short path differences up to approximately 3 km, the object could generally be identified as a gasholder, cooling tower, mast, etc., or a nearby hill. Weaker reflections (of the order of 10% or less) were observed having path differences of up to 40 km. Measurements of the direction and path difference of these signals were made at 14 widely spaced sites. The measurement error was estimated and the zones within which the reflecting objects lay were plotted. These zones were found to include hills and built-up areas.

4.2. Correlation between Results at Different Frequencies

Measurements were made, using an omnidirectional aerial mounted on a van at a height of 12 ft (3·7 m), of the relative magnitude of the reflected waves at two frequencies corresponding to the Light and Home Service programmes (89·1 Mc/s and 93·5 Mc/s). The measurements were made at forty-five points in two towns, one 43 km and the other 25 km from Wrotham. At any one site the relative magnitudes were of the same order on the two frequencies, and a satisfactory aerial position for one frequency was also satisfactory for the other.

4.3. Polarization of the Reflected Wave

Measurements were made of the plane of polarization of the reflected wave at eight sites. The greatest deviation of the plane of polarization from the horizontal was found to be 45°, and the average value was 12°.

5. MEASUREMENTS USING INDOOR AERIALS

In order to obtain information regarding the conditions present in normal domestic receiving installations, a series of measurements was made inside buildings, mostly private houses. Measurements were also made on all the floors of a large building in Central London. A dipole aerial was used both at picture-rail height and at table height, and in some of the tests a small portable aerial was used to simulate the "built-in" aerial in a domestic receiver.

Table 1 summarizes the order of magnitude of the delayed signals observed in measurements at eighteen scattered sites, shown in Fig. 5. In this table "long path-difference" is taken to be a path difference greater than 3 km, and "short path-difference" to be less than this. In most cases the long path-difference component was greater than 10 km. The mean values quoted are the mean of the results obtained on a dipole placed at picture-rail level on two adjacent walls, and at table level parallel to the walls. In finding the maximum values no restriction was placed upon the position of the dipole, except that positions of very low signal strength were disregarded.

TABLE 1

L.P.D. = long path-difference reflection
S.P.D. = short path-difference reflection

Site No.	Distance from Transmitter (km)	Relative amplitudes of reflected signals (%)				Remarks
		Mean L.P.D.	Mean S.P.D.	Max. L.P.D.	Max. S.P.D.	
1	35	16	9	50	20	Private House
2	34	5	5	12	12	Private House
3	29	1·5	9	12	23	Private House
4	36	7·5	6·5	15	10	Private House
5	37	5	7·5	10	13	Private House
6	24	13	12	18	18	Private House
7	24	6·5	12	7·5	27	Private House
8	35	9	1·5	25	5	Private House
9	61	11	15	13	17	Private House
10	61	3·5	6·5	7·5	13	Private House
11	60	10	9	20	20	Private House
12	41	5	3·5	8	7·5	Private House
13	26	5	6·5	7·5	10	Private House
14	37	3·5	7·5	7·5	20	Private House
15	34	7·5	5	14	13	Private House
16	35	7·5	3·5	15	8	Private House
17	34	3·5	1·5	13	10	Private House
18	35			13		1st Floor — Large Building in Central London
18	35			10	17	2nd Floor — Large Building in Central London
18	35			10	27	3rd Floor — Large Building in Central London
18	35			13		4th Floor — Large Building in Central London
18	35			13	33	5th Floor — Large Building in Central London
18	35			33	25	6th Floor — Large Building in Central London
18	35			14	29	7th Floor — Large Building in Central London
18	35			17	25	8th Floor — Large Building in Central London

In addition, measurements have been made at five sites, also indicated in Fig. 5, from which complaints of distortion had been received. In each case, the reflected wave had a path difference of 8 km or more, and a relative amplitude up to approximately 10% as received on a dipole aerial. It is interesting to note that one of these sites was only 14 km from Wrotham. Here the direct signal was attenuated by an intervening hill so that it became comparable in magnitude to a reflected signal having a path difference of 18 km.

From these investigations the following conclusions were drawn:

(a) In general the maximum relative amplitudes of the delayed signals were found to be greater inside buildings than outside because of the presence of standing waves. Both the direct and the delayed signals set up standing-wave patterns inside buildings, but because they arrive from

Fig. 5

Location of buildings in which reception conditions were investigated:

◎ General investigation — not in response to complaints (numbers correspond with those in Table I)

⊗ Investigation of complaints

different directions the nodes and antinodes of the patterns may not coincide. Consequently, it is possible to place an indoor aerial at a point where the direct signal is small while the reflected signal is large. Conversely, it is sometimes possible to obtain very good results with an indoor aerial by finding a position at which the reflected signal amplitude is a minimum. In a building the optimum position of the aerial may, however, be different for different frequencies.

(b) The use of a dipole at roof level does not necessarily reduce the ratio of the delayed to direct signal, although it does give a stronger resultant signal. Nevertheless if an aerial is to be installed without careful experiment, as must usually be the case in practice, it is believed that an aerial on the roof, or failing that, in the loft, will give better results than an aerial in a room.

(c) The delayed signal may sometimes be reduced by orienting the dipole in such a way that it is insensitive to the delayed signal, while not greatly reducing the amplitude of the direct signal. But in some cases (as, for example, when the direction of the delayed signal differs from the bearing of the transmitter by about 180°), this remedy is ineffective and a directional aerial must be used. Figs. 3 and 4 show the improvement which was obtained at a typical site by replacing a dipole by a four-element Yagi aerial.

(d) On the average there was no difference between the relative strengths of the delayed signals obtained with the built-in aerial and those obtained with a dipole placed in the same position, or fixed to the picture rail in the same orientation; but in a given room one of these aerials may sometimes be better than another.

(e) At a given site the reflected signal was occasionally stronger on one frequency than on another, but there was no average difference when all the sites were considered.

(f) There was sometimes considerable difference between the relative strengths of the delayed signals received in different rooms on the same floor of a building. No conclusive evidence was obtained to show that the effect was worse in rooms remote from the direction of the transmitter than in those nearer to the transmitter.

(g) When the input circuit of the receiver is imperfectly balanced and is connected to the aerial by a balanced feeder, or, alternatively, if the input circuit is correctly balanced and is connected to the aerial by an unbalanced feeder, "push-push" currents in the aerial lead usually tend to increase the relative magnitude of the reflected signals.

6. LISTENING TESTS

During some of the investigations inside buildings, listening tests were made, using both normal programme and piano music radiated for this purpose. It is

known that piano music is particularly susceptible to non-linear a.f. distortion, and for this reason the effect of multipath propagation is very noticeable with this type of music. Distortion was found to be more severe when reflected signals having path differences of 8 km or more were being received, presumably because of the higher order of the distortion products. At sites where very long path difference reflections (of the order of 30 km) have been present, distortion has been observed with reflected signal amplitudes as low as 2% of the direct signal. A variety of receivers was used and distortion was found to vary considerably from one receiver to another. In most cases domestic receivers gave more distortion than the receiver used for measuring purposes, which is relatively insensitive to amplitude modulation.

7. VARIATION OF MULTIPATH PROPAGATION WITH TIME

At one particular site measurements were made on 93·5 Mc/s at ten-minute intervals between 1300 and 1900 hrs for one day. Daily measurements were also made over a period of thirteen days. The maximum variation in relative amplitude of the reflected wave was from 13·3% to 17·5%. The relative phase of the direct and reflected signals at the carrier frequency remained constant to within $\pm 13^{\circ}$, indicating variations of only ± 12 cm in a path difference of 18 km. These small variations (±7 parts in 10^{6}) could have been accounted for by drift of the transmitter frequency within its specified tolerance.

8. CONCLUSIONS

The work summarized above constitutes only a preliminary survey of the problem. In order to arrive at a true assessment of the extent to which f.m. reception is impaired by multipath propagation, a much more thorough survey of the service area would be required. From the results given in Table 1, together with the results of some subjective experiments falling outside the scope of this report, it would seem that just-perceptible distortion, of piano music at least, may occur on commercial receivers, using indoor aerials, at each of the sites at which measurements were made. It would, however, be unfair to regard these results as representative of the area served by the Wrotham transmitter, since many of the observations were made within a few miles of the B.B.C. Research Department at Kingswood Warren. Much of this area has a poor propagation path from Wrotham along the ridge of the North Downs, while delayed signals often arrive by optical paths.

The effect of multipath propagation can be mitigated by the use of a high aerial, preferably directional. It is in any case much less serious if a receiver with a high degree of a.m. suppression is used. The use of such receivers during the experimental transmissions from Wrotham is undoubtedly the cause of the importance of multipath propagation being underestimated.

Work is now in progress to determine the dependence of the distortion caused by multipath propagation on the characteristics of the receiver. For this purpose, equipment has been developed to synthesize delayed signals in the laboratory. Another experiment for which preparations are being made is to use pulse transmissions to locate sources of reflection. A better understanding of this aspect of the problem may be of value in future planning.

It is hoped that information regarding reception at a widely distributed set of points in the Wrotham service area will result from the analysis of over 100 questionnaires completed by B.B.C. staff. Multipath propagation in the area served by the f.m. transmitter at Penmon has been surveyed by the Field Strength Section of Research Department using the equipment described in Section 3. The results are now being examined.

9. REFERENCES

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